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ABSTRACT

The majority of accidents and incidents in aviation can be attributed partially to poor decision making and judgement strategies. By gaining an understanding of aircrew decision strategies used in the operational environment of the cockpit, it may be possible to improve decision processes and outcomes for both expert and novice pilots. Naturalistic decision making (NDM) is proposed as an intuitive decision strategy used by experienced pilots to make operational decisions. The cockpit is considered a naturalistic environment due to characteristics such as experienced operators, multiple players and teams, dynamic conditions, shifting and competing goals, high risks, time pressure, and ambiguous or missing data. NDM strategies focus upon situation assessment and the serial evaluation of decisions through mental simulation. Decision aiding to improve situation assessment and decision training to impart awareness of the limitations and weaknesses (heuristics and biases) of human decision processes are both aimed at improving the overall decision performance of both expert and novice pilots. The overall aim is to improve aviation safety and reduce the number of accidents and incidents due to poor decision making and judgements.

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Executive Summary

Judgement and decision making errors are the primary factor in over 50% of general aviation accidents. However, through appropriate training, decision skills may be improved, thereby reducing the number of decision-related accidents. This report examines both the theoretical and practical aspects of operational aircrew decision models, before examining various methods such as decision aiding and decision training to actually improve the decision skills of both expert and novice pilots.

It has been discovered through several studies that experienced operators in their operational settings (including pilots) make many decisions using intuitive rather than analytical strategies. Naturalistic Decision Making (NDM) is one such style of intuitive decision making. Naturalistic decision making describes how experienced people make decisions in dynamic, naturalistic environments, under conditions of time pressure, dynamic goals, uncertain cues and high risk. All of these characteristics are found in aviation environments. The initial sections of this paper examine the principles of NDM, detailing theoretical perspectives that explain how the strategy works, and how such skills are acquired. Intuitive and analytical decision making strategies are compared and contrasted, highlighting the appropriateness of intuitive methods to operational settings such as aviation.

Analytical styles of decision making are appropriate in certain situations. These situations are usually those where the decision maker has specific goals, minimal time constraints, and a complete, correct set of information. When these conditions are met, it may be possible to make an optimal decision. However, these conditions are rarely met in operational aviation environments. In such naturalistic environments, intuitive styles of decision making (such as NDM) are more appropriate. Indeed, these are the descriptive styles of decision making employed by most experienced operators, such as aircrew.

Recognition-primed decision making (RPD) is one model of NDM involving decisions for which alternative courses of action are directly derived from the recognition of critical information and prior knowledge. These alternatives are serially evaluated, without the need for the comparison of options. Decision makers compare current events with previously experienced events and known rules stored in memory, recognising similarities to help them select appropriate reactions, judgments and decisions. Hence, the name, recognition-primed decision making. There are three basic phases to RPD; 1) situation recognition, 2) serial option evaluation, and 3) mental simulation.

Because naturalistic environments are dynamic, the decision maker must continuously reassess the situation in order to reassess the appropriateness of situation models and hypotheses. Once the pilot understands a situation an acceptable course of action is

often easily identified. Thus, situation assessment and awareness is a crucial and time consuming process for intuitive decision strategies. Situation assessment is also a prerequisite for good decision making, correlating positively with decision accuracy.

Mental simulation is the final process carried out before (or during) a decision action is implemented. The decision maker evaluates the course of action by acting out the decision in his/her mind, imaging how a sequence of events might unfold within a given context. The simulation often includes the successive steps to be taken, the potential outcome of these steps, the problems that are likely to be encountered, and how these problems can be handled. As a result of the simulation, the decision maker either rejects, modifies or implements the action. Because NDM emphasises satisfactory rather than optimal decision outcomes, the mental simulation is generally a rapid procedure, acting as a go/no-go check. If time is not available for a complete mental simulation, the decision maker will simply implement the decision action that experience has generated as the most likely to be successful and make subsequent changes as necessary to maintain a satisfactory outcome.

The importance of expertise and experience is explored throughout the paper, and the differences between expert and novice decision making are presented. It appears that only experienced pilots are capable of implementing RPD due to the reliance on memory traces and pattern recognition gained through experience, or possibly through training.

The final section of this paper addresses the improvement of decision strategies (and outcomes) though decision aiding and decision instruction, and examines how some areas of NDM and RPD may be able to be taught to novices and inexperienced pilots. Although there has been little work done to formulate teaching strategies for NDM and RPD, some ideas are presented. It appears possible to teach novice pilots at least the basics of NDM, which they are then able to develop.

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Peter Simpson is a Professional Officer working in Human Factors within Air Operations Division of DSTO. He has a BSc (Hons) in Aviation and a MSc (Dist) in Human Factors and Ergonomics from Loughborough University (UK). During his five years at DSTO he has worked in areas such as workload and operational performance, effects of automation, decision making, ergonomics, display design, and visual research with NVGs. Peter also holds a Commercial Pilots Licence.

Contents

1. Introduction

Over the past 20 years, judgement and decision making errors have been a causal factor in the majority of general aviation accidents (Wiggins & O'Hare, 1993), and this trend is not expected to change in the immediate future (Diehl, 1991). Many of the accidents have involved pilots pressing on into deteriorating weather conditions. The main causal factors in such accidents are decision making, judgement error and pilot attitude (Rockwell, Roach & Griffin, 1981; Wiggins & O'Hare, 1993). When these three factors are combined it can result in an unrealistic situation assessment (O'Hare, 1990), and a resulting accident or incident. However, decision skills may be improved through appropriate training, thereby reducing the number of decision-related accidents (Kaempf & Klein, 1993).

Although decision making has been studied extensively in general psychology (Beach & Mitchell, 1978; Einhorn & Hogarth, 1981; Gick & Holyoak, 1980; Tversky, 1972), much of this research has dealt only with single stimulus mathematical and statistical models, with little research dealing specifically with real world environments, such as aviation. Until recently, most research was based upon the "classic" analytical and systematic methods of decision making such as multi-attribute utility analysis (MAUA) and elimination-by-aspects (Edwards, 1987; Tversky, 1972).

Beach and Lipshitz (1993) stated that real life decision tasks differ markedly from the tasks for which classical, analytical decision theory was designed. Such analytical methods provide training for a single type of decision only, where the pilot has ample time to generate multiple options and evaluate each of these on known dimensions in a static environment (O'Hare, 1992; Kaempf & Klein, 1993; Rouse & Valusek, 1993). These analytical approaches are cumbersome and time consuming, and are therefore unsuitable for most aviation decision and judgment tasks.

Since the late 1980's, intuitive decision making models that are more appropriate for aviation have been developed. Intuitive processes are those of low cognitive control, carried out in the mind immediately, without deliberation, reasoning, or conscious awareness (Hammond, 1988; Lipshitz, 1993). Because these intuitive, automatic and semi-automatic cognitive processes generally involve rapid rates of data processing, they are often well suited to time-pressured environments. Naturalistic Decision Making (NDM) is a well-documented, intuitive decision strategy (Klein, 1989). Models of NMD include Klein's (1989) Recognition Primed Decision Making (RPD), in addition to O'Hare's (1992) "ARTFUL" decision maker. These models represent a new direction in aeronautical decision making, as they take decision analysis out of the sterile, predictable laboratory, and examine it in dynamic, naturalistic environments and operational settings, where time is limited, goals are dynamic, data are questionable, and decision consequences are high (Kaempf & Klein, 1993).

The decision strategy chosen depends on the problem type (familiarity, ambiguity, complexity, stability), the environment (time, risk, resources, problem significance, irreversibility), and the characteristics of the decision makers (expert, novice, motivation, knowledge, ability) (Beach & Mitchell, 1978; Hammond, 1988; Orasanu,

1993). Most cockpit situations involve a combination of time constraint, risk, dynamic goals and environment, and professional pilots (intermediate and experienced), thereby making NDM and RPD strategies better suited than analytical methods.

1.1 Analytical Decision Processes

Analytical approaches rely on the careful, deliberate analysis of cues, with the pilot generating a wide range of options, and concurrently evaluating and comparing evidence, then choosing the optimal course of action. Because the decision maker generates a wide range of responses and counter-responses, these processes usually require large amounts of time, resources and cognitive expenditure. The models and tasks formulated are usually singular, well defined and straightforward, as are the alternatives (Hammond, 1988; Rouse & Valusek, 1993). Although this type of decision strategy has a place for some decisions and situations, (e.g., buying a car, deciding on employment candidates), the analytical approach is largely inappropriate in naturalistic environments, and an intuitive approach appears to be more appropriate.

Analytical strategies deteriorate when confronted with time pressure. Klein and Klinger (1991) stated that even under low time pressure, analytical strategies require extensive work and lack flexibility. Several studies on experienced engineers found that even under no time pressure, they still relied heavily on NDM type strategies, regardless of information characteristics, problem difficulty, familiarity and structure (Hammond, Hamm, Grasia & Pearson 1987; Klein 1989). A study by Zakay and Wooler (1984) found that training in analytical methods of decision making did not improve the quality of decisions when subjects were under time pressure. In fact, Hammond et al. (1987) found that intuitive cognition can outperform analytical processes, and is less likely to result in extreme errors. Beach and Lipshitz (1993) found no evidence that classic or formal decision models improve decision performance. Wickens, Stokes, Barnett and Hyman (1993) stated that intuitive strategies are less prone to degradation under stress, because retrieval of familiar information from long term memory may be relatively immune to the cognitively degrading effects of stress. Hammond et al. (1987) also stated that it is difficult for ambiguous cues, inaccuracies, dynamic environments, conflicting goals, group processes and expertise to be factored into analytical judgment and decision making process. Intuitive decision theories (such as NDM) are able to account for all of these variables.

1.2 Intuitive Decision Strategies

Although intuitive decision strategies have found acceptance in the 1990's, little previous research had been conducted with such strategies. As late as 1978, Beach and Mitchell (1978) discussed non-analytical (i.e. intuitive) processes as being fairly simple, pre-formulated rules such as, "eeny meeny miney mo", flipping a coin, or well known

sayings like "red sky at night, sailors delight". The use of the term "non-analytical" rather than "intuitive" was a common occurrence in many contemporary papers. Rather than giving an acceptable scientific definition of intuitive strategies, they were simply defined as being the opposite of analytical strategies. Such points highlight the lack of serious research previously conducted on intuitive strategies.

A similar situation is found with judgement and decision making in dynamic task environments. Hammond (1988) stated that of the many thousands of articles and journals on decision making, dynamic situations (i.e. naturalistic environments) have hardly been touched; virtually all research has focussed on static tasks. These points help to further emphasise the general progress that has been made in the field of intuitive theories with NDM and RPD models since the early 1990's.

NDM and RPD are descriptive (rather than normative or prescriptive) approaches to decision making, as they describe how people actually choose between options, rather than how they should choose (Jonsson, 1991; O'Hare, 1992). Brehmer (1990) stated that naturalistic decisions and environments must be studied by descriptive models, yet according to O'Hare (1992), there has been little effort put into developing descriptive approaches to aeronautical decision making.

Many analytical theories of decision making, including most aeronautical decision making strategies have so far used a structured, prescriptive approach (e.g., DECIDE, SADIE, IMSAFE), and thus, are concerned simply with inputs and outputs (Maule & Svenson, 1993). The correct choice or outcome indicates good judgement, and the wrong choice or outcome indicates poor judgement. The cognitive process a person uses to reach these outcomes is ignored, and option generation is treated as a "cognitive black box" (Kaempf & Klein, 1993). Process approaches however, are concerned with how decisions are made in terms of the underlying psychological and cognitive processes that produce the outcome (Maule & Svenson, 1993; Orasanu & Connolly, 1993). Hence, process approaches can be seen as exploring the cognitive black box. Process analysis of decision making is much more suited to the study of NDM and RPD.

1.3 Cognitive Continuum Theory

The cognitive continuum theory states that intuitive decision making strategies occupy one end of the cognitive continuum, with analytic strategies at the other end, and quasi-rational decisions and judgements in the middle (Hammond et al., 1987; Hammond, 1988, 1993). As suggested by Figure 1, NDM and RPD are at opposite ends of the continuum to traditional, analytical and systematic decision making strategies (Hammond, 1993). Once a cognitive process has been located on the cognitive continuum, it will be found to interact in predictable ways with various task conditions, such as time period, cue characteristics, cognitive control, errors and rate of data processing (Hammond, 1993; Hammond et al., 1987). Knowledge of the locus of a task on the task continuum index makes it possible to predict the corresponding cognitive processes of the decision maker (Hammond, 1988). For example, tasks

requiring large amounts of information to be processed in short time periods induce intuitive methods (Lipshitz, 1993). Cognitive activity can oscillate about the cognitive continuum between intuitive and analytical as the task conditions change.

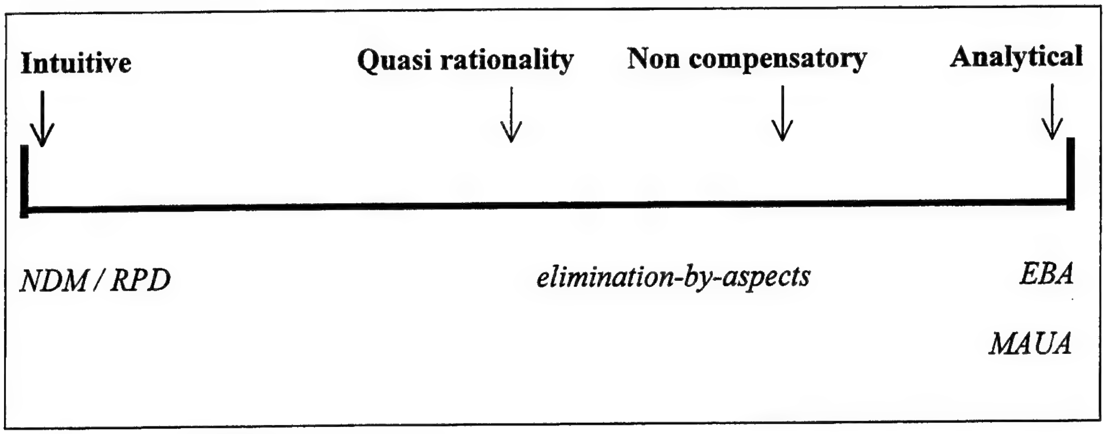

Figure 1. Cognitive Continuum indicating locations of several decision making strategies and examples of each.

The cognitive continuum theory also offers important predictions concerning human error. In comparison to errors produced by perception and intuition, analytical processes produce fewer errors, but when they do occur the errors are more serious (Hammond et al., 1987). Both Lipshitz (1993) and Hammond (1988) stated that judgements and decisions are most accurate when the location of cognitive processes on the cognitive continuum corresponds to the location of the decision task on the task continuum. Hammond (1988) even suggested that operators who employ intuitive judgement in response to task conditions designed to invoke intuitive cognition will be more accurate in their judgements and decisions than those whose methods are analytical in these circumstances. He stated that this conclusion runs counter to previous research that had argued for analytical solutions in all possible circumstances.

2. NDM and RPD

Briefly, NDM is how real people (including intermediates, professionals and experts) make decisions in complex, real world environments (see Fig. 2). Brehmer (1990) and Klein et al. (1993) summarised the key features of NDM (and these are easily contrasted to analytical decision making);

- NDM requires a continual series of decisions, rather than a single, one-off decision.

- The decisions are interdependent, with one decision affecting those that occur after.
- The environment and conditions are dynamic, continually changing both autonomously, and as a consequence of the decision maker's actions.
- The decision maker must make choices and judgements in real time.
- The goals and tasks are often ill defined, dynamic and competing.
- The decision makers are usually knowledgeable, experienced, and professional.

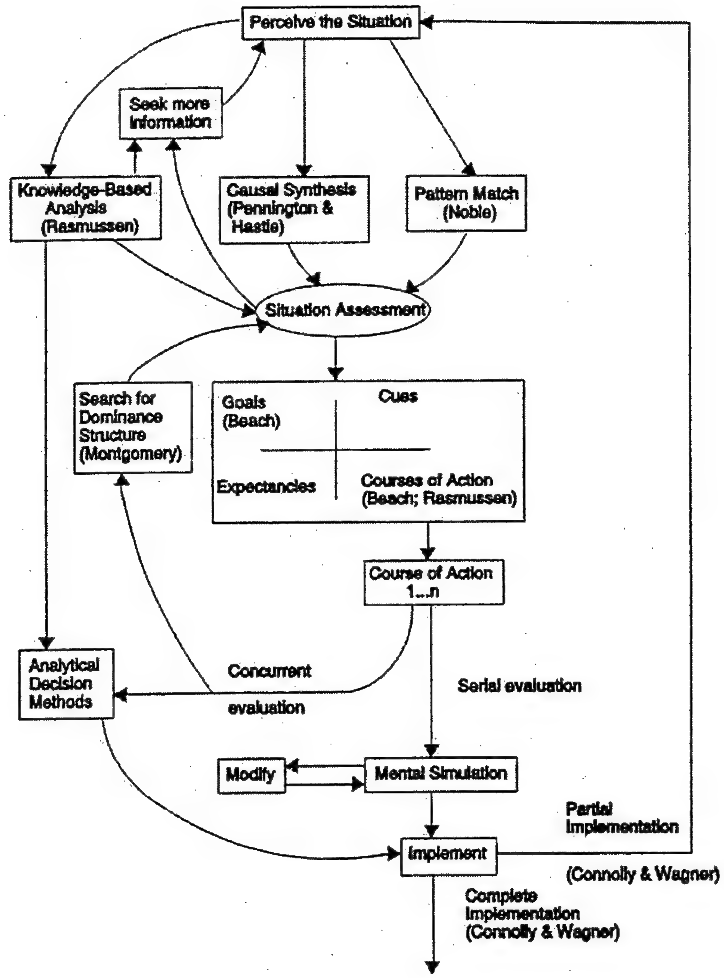

Figure 2. Synthesised process model of NDM (Klein, 1993b, p. 391).

RPD is one model of NDM involving decisions for which alternative courses of action are directly derived from the recognition of critical information and prior knowledge (Klein, Calderwood & MacGregor, 1989). These alternatives are serially evaluated, so there is no need for the decision maker to compare options. In most operational

environments the aircrew are experienced (or intermediate) professionals. Due to the experience of the decision maker, in many cases the first or second option generated is a workable one, and hence is chosen. Decision makers compare current events with previously experienced events and known rules stored in memory, recognising similarities to help them select appropriate reactions, judgments and decisions. Hence, the name, recognition-primed decision making. There are three basic phases to RPD (Lipshitz, 1993); 1) situation recognition, 2) serial option evaluation, and 3) mental simulation. These processes are described in a later section

An example of RPD might be a pilot immediately recognising a pattern of instrument readings and other conditions (both internal and external to the aircraft) as attributable to carburettor icing, without the need to go through a time consuming, analytical reasoning process. The cognitive activity that allows a person to match events and knowledge perceived, with an already established template, is known as pattern or feature matching (Hammond, 1988). Such templates may be instilled via training or experience.

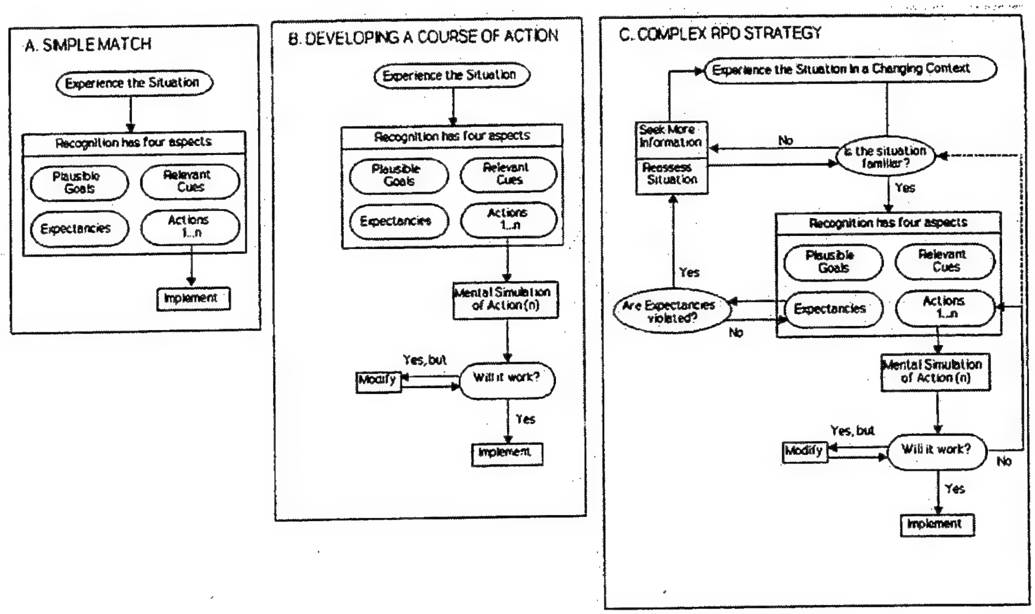

Figure 3. Klein's three RPD models of various NDM situations (Klein, 1993a, p. 141).

Klein's (1993) RPD model of NDM (Fig. 3) includes several variants according to decision complexity. The simplest case is where a situation is recognised and the obvious reaction is implemented. A more complex model involves the decision maker having to mentally simulate the reaction to evaluate it. The most complex case is where the mental simulation reveals flaws, and a modification must occur. These three cases suggest that NDM can be used in most decision events a pilot faces, as long as the pilot can match what they are currently experiencing to what they have previously experienced or learnt.

O'Hare (1992) referred to NDM and RPD strategies activating "if-then" or "condition-action" rules. Once a situation or condition has been assessed and recognised as "that type", then the appropriate reaction is implemented. For example, IF condition x is met, THEN implement action y. The decision is recognition primed, as the pilot may have previously encountered the situation, or something similar to it. The previous encounter may have been in either an operational or training (including simulator) environment. These types of condition-action rules and relationships are relevant to aviation where there are many standard operating procedures and well-practised responses to situations and conditions.

The characteristics of naturalistic environments have been described by several researchers (Brehmer, 1990; Kaempf & Klein, 1993; Orasanu & Connolly, 1993). These characteristics are summarised in Table 1, and the key features of NDM and RPD decision making are summarised in Table 2. Many of the points listed are easily contrasted to the components of analytical decision making.

Table 1. A Summary of the Characteristics of Naturalistic Environments

- *uncertain, ambiguous or missing data* - data may even be incorrect or conflicting.
- *Ill-defined and ill-structured goals and tasks*
- *shifting and competing goals* - situation is rarely dominated by single, well understood goals, instead goals may be ill-defined, incompatible and dynamic
- *uncertain, dynamic environments* - situations are not static, straightforward or unambiguous
- *action/feedback loops* - a series of events and decisions will alter subsequent goals and actions
- *time pressure* - leads to decision making involving heuristics, biases and cognitive shortcuts. Aircraft may travel over 15km in 1 min, thus time is crucial
- *high stakes and risks* - consequences of error are high, even to the point of life/death
- *multiple players and teams* - many aircraft have 2 or 3 pilots, as well as engineers and flight attendants, in addition to ATC, other aircraft, and ground staff to be considered
- *organisational goals and norms* - the overall mission statement or goals of organisations exert pressure that may conflict and bias the situation
- *experienced decision makers* - novices are rarely studied in NDM, as most professionals are experienced or intermediates.

Table 2. A Summary of the Key Features of NDM and RPD

- Serial generation and evaluation of options, rather than concurrent evaluation and deliberation
- First option chosen is usually reasonable and workable, rather than semi-random generation and selective retention of many options.
- Satisfactory options and outcomes rather than optimal ones
- Evaluation through mental simulation, rather than maths, statistics or comparison analysis
- Focus on situation assessment, rather than decision events (such as option ranking)
- Decision maker is primed and committed to act, rather than waiting for a complete analysis

(Adapted from Klein & Klinger, 1991; Klein, 1993)

2.1 Situation Assessment and Mental Simulation

2.1.1 Situation Assessment

Decision tasks can be divided into *situation assessment* and *actual decision making* (Kirschenbaum, 1992). This is another area where the underlying principles between intuitive and analytical decision processes differ. Orasanu and Connolly (1993) reported that the major factor that distinguishes expert from novice decision makers is the experts' situational awareness and agreement ability, not their actual reasoning and decision processes. Most analytical decision theories focus upon generating the optimal option and the actual selection of the best alternative, whereas NDM and RPD strategies focus upon the earlier stage of situation assessment with very little time spent generating alternatives (Mosier, 1991; Orasanu & Connolly, 1993). This is because in time-pressure situations, a decision may need to be made before the nature of the problem is properly defined or understood, hence the optimal decision outcome may never be known. Furthermore, dynamic goals and changing conditions mean that the optimal outcome is often dynamic in itself.

Because naturalistic environments are dynamic, the decision maker must continuously assess the situation in order to reassess the appropriateness of situation models and hypotheses (Kirschenbaum, 1992). Thus, situation assessment and awareness is a crucial process for intuitive decision strategies. Situation awareness is a prerequisite for good decision making, correlating positively with decision accuracy (Klein, 1989; Mosier, 1991; Noble, 1993). Once the pilot understands a situation an acceptable course of action is often easily identified (Kaempf & Klein, 1993).

Figure 4 displays a cognitive model of the situation assessment stage of RPD. It outlines how experienced decision makers use previous experiences to assess a situation and identify appropriate actions. Noble (1993) stated that it is during the situation assessment phase that a decision maker interprets the meaning of the situation, inferring the reasons why the situation appears as it does, assesses the inherent risks and opportunities, and identifies the actions to minimise these risks and maximise the opportunities. These actions are identified by comparing the situation with previously experienced reference situations encoded in memory. Each reference problem has general solution methods and situation conditions that apply to it. The reference problems that match the current situation are activated when the problem solution methods associated with the activated reference problem become candidate actions. Table 3 describes the important role that situation assessment has in NDM.

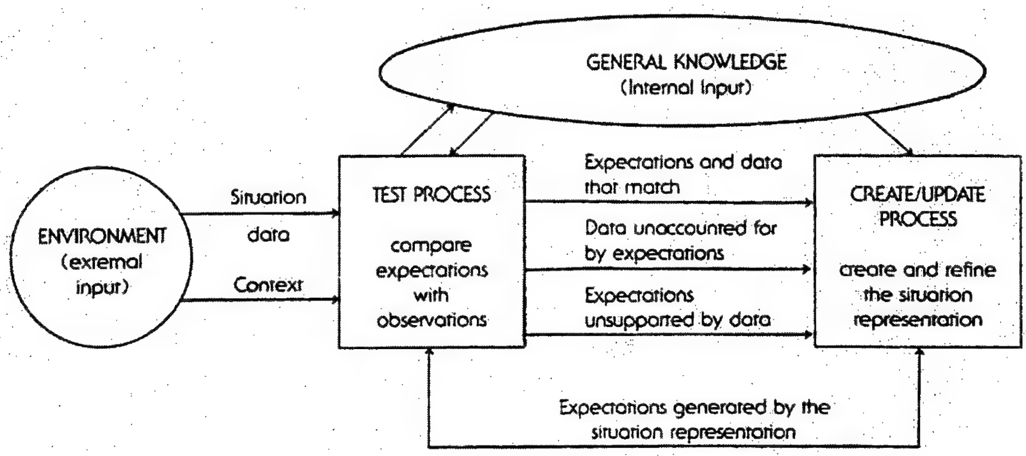

Figure 4. Noble's model of situation assessment in NDM/RPD. (Noble, 1989, cited in Lipshitz, 1993, p. 106)

Table 3. The Role of Situation Assessment in NDM

- It helps to understand the types of goals that can realistically be accomplished given the situational conditions.
- Situation assessment also allows the decision maker to increase the salience of important cues
- It helps for expectations that can serve as a check on the accuracy of the situation assessment.
- It allows typical actions to be identified

Adapted from Klein (1993)

Therefore, good situation assessment allows the information available about a situation to be compared to stored encounters, and a suitable working model of the true situation can be developed (Kirschenbaum, 1992).

Brehmer (1990) stated that "to control a system, a .... decision maker must have a model of the system it seeks to control" (p.265). Therefore, effective judgement and decision making cannot take place unless a suitable model or hypothesis has been generated. When the correct model or hypothesis is generated - and there may be more than one available - the pilot can then plan ahead, allowing proceeding behaviours and choices to be guided by expectancy and hypothesised schemas (Kirschenbaum, 1992). If an incorrect model is developed, the results and actions that follow can be disastrous (e.g., British Midlands B737 crash at Kegworth, USS Vincennes shootdown of friendly aircraft, American Airlines B757 crash at Cali, Columbia). The RPD model (Fig. 1) suggests that decision makers may fail due to faulty situation assessment and mental simulation stemming from incorrect models.

Mosier (1991) found that many aircrews did not even wait until they had a complete understanding of their situation to make and implement decisions. Rather, they made recognition, reflexive judgements based upon a few critical items of information. Continual situation assessment was then used to verify the decision's acceptability. If the course of action needed to change, a second option would be generated and implemented in the same manner. This process emphasises the importance of situational assessment and action/feedback loops.

2.1.2 Mental Simulation

The other important phase of RPD - mental simulation - is the final process carried out before a decision action is implemented, or during its implementation. The decision maker acting out the decision in his/her mind, imaging how a sequence of events might unfold within a given context, thereby, evaluating the course of action via mental simulation (Klein, 1993). The simulation often includes the successive steps to be taken, the potential outcome of these steps, the problems that are likely to be encountered, and how these problems can be handled (Lipshitz, 1993). Klein (1993) stated that mental simulation is generally used to assess whether the decision maker's understanding or model of a situation is logical, and to determine what may go wrong if a decision action is implemented. As a result of the simulation, the decision maker either rejects, modifies or implements the action (as per Figure 2). Because NDM emphasises satisfactory rather than optimal decision outcomes, the mental simulation is generally a rapid procedure, acting as a go/no-go check. If time is not adequate for a complete mental simulation, the decision maker will simply implement the decision action that experience has generated as the most likely to be successful and make subsequent changes as necessary to maintain a satisfactory outcome (Klein, 1993).

Large transport aircraft usually have two or three crew members in the cockpit. In this situation, mental simulation is important in ensuring that the crew members all share the same mental model (Orasanu & Connolly, 1993). Only when the crew members are

all working together on the same problem can team decision making be effective and efficient. Shared mental models allow crews to function efficiently because they serve as an organising framework, allowing the crew to anticipate events as well as each others actions; vital for effective NDM and RPD (Orasanu, 1993). Shared mental models can only be achieved through good crew communication and interaction.

3. Applied NDM

There have been several studies of professionals in their operational settings using NDM and RPD strategies. These include studies on fireground commanders (Klein, Calderwood & Clinton-Cirocco, 1986), wildland firefighters (Taynor, Klein & Thordsen, 1987), rotary wing aircraft (Thordsen, Klein & Wolf, 1992), battle ship commanders (the AEGIS cruiser commander – Kaempf, Wolf, Thordsen & Klein, 1992), tank platoon leaders (Brezovic, Klein and Thordsen, 1987), and design engineers (Klein & Brezovic, 1986). The following discussion centres on the fireground commanders (FGCs) study because it is thoroughly documented (Klein et al., 1986). The findings of all the studies are very similar, supporting what has been described in this report.

3.1 The Fire Ground Commanders (FGCs)

The FGCs reported that their decision making processes did not involve "making choices", "considering alternatives", or "assessing probabilities". Rather, they stated that they were acting and reacting on the basis of prior experience; the basis for their decisions was the ability to recognise and appropriately classify situations (ie., situation assessment). With the use of mental models, plans were generated, monitored and modified as the situation and conditions changed. Using their experience, the FGCs usually generated a workable option as the first to come to mind. There was no extensive option generation, nor was there any concern to generate the optimal choice. The concept of serial evaluation is important, as the FGCs reported that after mental simulation, if a new decision or course of action is needed, the next most workable or likely reaction is selected. This mental search continues serially until a workable solution is identified. Rarely are two decisions evaluated concurrently, and the FGCs stated that the reason for this is simply time constraint. In the time it takes to generate and analytically compare two options, the situation may have changed, and the fire may possibly get out of control. If conscious deliberation was entered into at any stage, it was in terms of classifying and articulating the nature of the decision problem itself.

There is continual emphasis and reliance on situational assessment and mental simulation[1]. Once the FGCs recognised it as "that type of problem" or "that specific problem", they could recall the typical response to be implemented, demonstrating O'Hare's (1992) IF-THEN hypothesis. Due to this recognition based reaction, the FGCs rarely considered more than one option when making a decision. Once the situation was recognised, it sensitised the decision maker to important (not always salient) cues, and helped them build appropriate working models of the situation. The FGCs could then mentally run through their plans and models to evaluate the feasibility of their implementation. If any problems were foreseen, the option would be modified or rejected as discussed previously.

Because the FGCs were continually assessing the situation and modifying their plans as needed, they were always primed to act and react. The FGCs could respond immediately to changes in the action/feedback loop, and unlike novices, they knew and could accept when to alter plans. Because the FGCs did not need to wait for complete, analytical analysis and outcomes of the situation, they could respond rapidly to changes. This often meant the difference between containing the fire or not.

4. Decision Optimality

When emphasising how unsuitable analytical methods can be for aviation, Beach and Mitchell (1978) stated that such methods can work well when there is ample time, information and money to execute the strategy - a situation that pilots rarely find themselves in. The conflicting, incompatible goals of aviation almost never allow for a single, optimal decision choice to be made. However, the optimal decision is usually not necessary, rather, a good decision is just as acceptable and leads to a similar outcome without large amounts of time and resources being (Einhorn & Hogarth, 1981).

Pilots generally implement the first workable decision, rather than comparing many decisions for optimality (Kaempf & Klein, 1993; Klein & Klinger, 1991). There is little evidence that changing a decision from good to optimal will result in any more safety or efficiency (Orasanu, 1993). According to Beach and Mitchell (1978), people choose the decision making strategy that requires the least resource investment for a satisfactory solution (not an optimal one). In operational environments it is important to expend the least personal resources (also known as cognitive economy) as there are often more situational and circumstantial demands than the single decision task.

In naturalistic situations there is often no optimal situation that can be reached. An optimal decision outcome implies a single, well-defined goal has been stated, and the

[1] For an excellent example of the importance of situation assessment and mental simulation, see Kaempf, Wolfe, Thorsden & Klein's (1992) study of the commander of an AEGIS cruiser deciding whether or not to engage enemy aircraft.

situation remains stable and unchanging. One of the features of dynamic environments is that goals are dynamic and often competing. In aviation, there are many such dynamic, competing goals; company policy, customer comfort and convenience, safety, profit and timeliness. In such a situation it is impossible to completely satisfy all of these areas, and therefore, an analytical strategy is wasted.

Even the concept of optimal and acceptable outcomes is not totally applicable for naturalistic settings, as these concepts assume that a single decision will determine a situation's outcome. This may be true in the laboratory, but in everyday situations, decisions are embedded in larger tasks or goals that the decision maker is trying to accomplish (Orasanu & Connolly, 1993). A situation is usually made up of many small tasks and decisions, therefore, making a single decision is not an end in itself, but rather one step on the way to achieving an overall goal (Means, Salas, Crandall, Jacobs, 1993). Decision making becomes a matter of providing direction for the continuous flow of behaviour and monitoring one's progress toward some goal, rather than discrete episodes involving choice dilemmas (Brehmer, 1990).

5. Heuristics and Biases

Intuitive decision making styles are used when time is limited. Klein et al. (1989) suggested that NDM and RPD are valuable in operational settings where there is little time for conscious deliberation, as a considerable amount of deliberation in NDM process is semi- and sub-conscious. Such time limitations, coupled with semi- and sub-conscious processes result in heuristics and biases entering the decision making process. Heuristics and biases cause people to sample and process information in a selective, subjective manner (Evans, 1990). Heuristics are quick and intuitively sensible rules of thumb that allow people to summarise information and situations rapidly with their current knowledge (Bootzin, Bower, Crocker & Hall, 1991). Biases are often a result of heuristics, and are predispositions on the part of the individual to respond in certain ways (Jonsson, 1991).

The importance of heuristics in making inferences has long been recognised. People rely on heuristics to reduce the complex task of assessing probabilities and predicting values (Einhorn & Hogarth, 1981; Tversky & Kahneman 1974). In demonstrating the importance of heuristics to aviation decision making, Orasanu (1993) stated "cockpit decisions are heuristics" (p. 139). In naturalistic environments, heuristics may be both less effortful and more accurate then classical decision models (Cohen, 1993a). Tversky and Kahneman (1974) stated that heuristics are quite useful and highly economical, but can sometimes lead to systematic and predictable errors. Such errors may include sampling only salient data, ignoring data that conflicts with initial situation assessment, and basing situation assessment and diagnosis on recently occurring events because they "come to mind" easily.

Despite these known errors, the complex nature of naturalistic environments results in a person having two alternatives - either build optimal models by making environmental simplifications, or build heuristic models that maintain environmental realism, yielding adequate rather than optimal decisions (Einhorn & Hogarth, 1981). Often the better of the two choices is to use the cognitively-efficient heuristics. According to Einhorn and Hogarth (1981), heuristics exist because they serve useful functions, but above all else, their benefits outweigh their cost. However, heuristics and biases are not cognitive processes that a person can choose to implement or not. They are engaged on a sub-conscious, automatic level. Thus, by its very nature, the human reasoning process is error-prone and sub-optimal (Cohen, 1993,).

Some of the more well-documented heuristics and biases include (Evans, 1990; Mosier-O'Neill, 1989; Tversky & Kahneman, 1974; Wickens, 1985);

- the representative heuristic
- cue reliability or the "as if" heuristic
- cue salience or vividness
- the confirmation or anchoring bias
- negative evidence
- the availability heuristic

A well-documented cognitive shortcut that pilots use in NDM is data simplification, where technical data is summarised into a few simple statements. This data simplification is another form of cognitive efficiency. Studies by Layton and McCoy (1989), Cohen (1987), Kuipers, Moskowitz and Kassirer (1988), and Beck (1987, cited in Wiggins & O'Hare, 1993) have all revealed similar findings regarding decision makers in naturalistic environments. The decision task is often simplified by focussing on a few select aspects of the information available to the pilot (O'Hare, 1992). This is neither a good nor bad situation, rather, it is an effective simplification. Whilst the optimal outcome will probably not be realised, an acceptable outcome can be reached with much less resource expenditure and time wastage. Time is a highly valued resource in most in-flight decision scenarios.

Layton and McCoy (1993) gave the following example of how pilots focus on select aspects of data and information. Rather than a detailed understanding of weather situations, pilots tend to sum up the situation in terms of positives or negatives at a few salient points en-route. The pilots are then attracted by the positives and repelled by the negatives. According to O'Hare (1992), the risk of pressing on into deteriorating weather may be perceived in terms of "fairly low", or "much better than" the risks of a precautionary search and landing. Such terms better capture the nature of real life uncertainty and ambiguity that is characteristic of NDM. Pilots prefer not to think about uncertainty or ambiguity in numerical or probabilistic terms, but prefer to deal with a single concrete representation of the situation (Cohen, 1987). Pilots often prefer qualitative to quantitative reasoning to aid in NDM and RPD situations (O'Hare, 1992).

6. Expert & Novice Use of NDM

Good decision making is an acquired skill (Kirschenbaum, 1992). NDM and RPD are closely linked with the expert-novice relationship because the basis to such decision strategies is intuitive cognition and memory. A person uses prior experience, encounters and knowledge to help them deal with the current judgement decision. The decision making process is relatively rapid, as either the current situation is in some way recognisable to another, or it is not. According to Hintzman (1986), each event experienced produces a separate memory trace, with knowledge derived from the pool of episodic memory traces at the time of retrieval. A retrieval cue contacts all the traces simultaneously, activating those that are similar to the cue. The information retrieved from memory reflect the summed content of all activated traces. A novice or inexperienced pilot, no matter how relatively skilled they are, simply will not have enough templates of situations, encounters or circumstances in memory to pattern match current situations. Thus a novice's use of NDM or RPD is limited.

The importance of experience and expertise in NDM and problem solving has been well documented (Kirschenbaum, 1992; Klein et al., 1989; Lipshitz, 1993; Means et al., 1993; Mosier, 1991; Orasanu & Connolly, 1993; Wickens, 1987; Wickens, Stokes, Barnett, & Hyman 1993). Summed briefly, these studies have revealed differences between experts and novices in how problems are interpreted, what strategies are devised, what information is used, situation understanding, memory recall for critical information, use of heuristics, plausible goal setting, recognising inappropriate reactions, and speed and accuracy in decision making and problem solving. Generally, experts can identify underlying causes to problems and have deeper, more complex models and understanding of the problem and environment. However, the biggest difference between experts and novices, especially in terms of NDM, is their ability to assess and evaluate the situation, rather than their ability to generate and choose among options (Orasanu, 1993).

6.1 Information and Cue Sampling

When discussing experience and NDM, information and cue sampling are one area that experts and novices differ in. The human memory and attention system are limited, and deteriorate when overloaded (Wickens, 1987). Therefore, when a person samples too much information, it degrades rather than improves decision making (eg. Omodei & Wearing, 1997). Experienced decision makers know how much information they need to make a correct situation assessment and following suitable decision. The experienced decision maker needs only to gather enough information to recognise the situation as similar to a previous encounter or not (Wiggins & O'Hare, 1993). Better information gathering strategies lead to better situational understanding, which in turn lead to better decision making. Inexperienced pilots may waste time and effort examining as much information as possible. Much of this sample information is relatively unimportant, as novice pilots are not bounded by the experience of limited previous outcomes. Inexperienced pilots tend to focus their search on the most salient cues, not necessarily the most important cues. In contrast, experienced pilots are able to

seek critical information (not necessarily the most salient), generating a small set of plausible diagnoses, options and hypotheses (Lipshitz, 1993; Orasanu & Connolly, 1993). Therefore, experts tend to use a smaller quantity, but greater quality of information meaningful to good situation assessment and decision making (Kirschenbaum, 1992).

Experts use more focussed information searches associated with better structured knowledge schemas. A study by Beck (1987, cited in Wiggins & O'Hare, 1993) compared weather related decision making in experienced and inexperienced pilots. The experienced pilots possessed more effective search strategies, and were more accurate. Klein (1993) found that experienced people generally used recognition-primed methods to retrieve a single likely option, whereas novices were more likely to use an analytical approach, systematically comparing multiple options. Much of the evidence in this report suggests that the novice's approach to decision making is cognitively inefficient and does not produce a more effective outcome.

6.2 Procedural Knowledge

Expertise in pilot decision making is heavily related to procedural knowledge (Wickens et al., 1993). Such decision making is also related to Rasmussen's (1986) skill-based and rule-based knowledge. Beach and Mitchell (1978) stated that a person's knowledge (or lack of knowledge) has the greatest influence on the decision strategy selection and the success of the chosen strategy. They also emphasised the importance of the ability to exercise this knowledge. These two characteristics of the decision maker display the importance of experience or expertise to intuitive decision making processes. Lipshitz (1993) reiterated this by stating "The RPD model underscores the crucial role of domain specific knowledge or experience in proficient decision making; no step in the (RPD) model can be executed effectively without such knowledge" (p. 109).

Like many other complex, high risk, socio-technical systems, aviation is bound by many procedures, rules, regulations, standard operating procedures (SOPs), and pre-planned responses. For many decision and judgement tasks, a SOP or regulation prescribes the appropriate responses, instantly limiting five or six choices to one or two. It is the experts' well-developed procedural knowledge that allows them to recall all the regulations and SOPS that effect a decision, rapidly limiting the choices available, and hence, rapidly reducing cognitive expenditure. Experienced aircrew can therefore solve problems faster by considering fewer alternative solution paths.

In contrast, a novice pilot has only rudimentary procedural knowledge, and will spend a greater amount of time recalling and applying all relevant regulations and SOPS. Therefore, in novices, the initial cues may not trigger a recall of a manageable number of possible schemas or rules (Kirschenbaum, 1992), causing a possible information overload and sense of confusion, "paralysing" the inexperienced decision maker (Lipshitz, 1993). Again, this emphasises the importance of situation assessment in highlighting the appropriate course of action. However, if the incorrect problem or course of action is diagnosed, then the incorrect SOP or regulation will be

implemented, leading to a potentially fatal situation (Kaempf & Klein, 1993). Such was the case with the Kegworth disaster, where a British Midlands B737 aircrew shut down the wrong engine due to incorrect situation assessment. Skill-based knowledge was used to apply the well-known rules and procedures for engine shutdown. The correct engine shutdown SOP was implemented, but it was based on an incorrect decision due to an incorrect situation awareness. The aircraft eventually crashed a few miles short of the runway.

As has been shown by several researchers (Chase & Simon, 1973; deGroot, 1966; Kirschenbaum, 1992; Newell & Simon, 1972), experts tend to view displays, events or situations in terms of recognisable sets or patterns and learn to associate set moves, reactions and procedures with each pattern. These patterns easily come to mind, negating the need to go through random search-and-test processes for all possible solutions (Means et al., 1993). This pattern further reduces the workload required to gather and process situational information, and allows for rapid reactions. Again, this highlights the importance of situational assessment and awareness to NDM.

Expertise is highly domain specific, and does not transfer easily. A chess grand master uses RPD to choose a move from tens of thousands of recognisable sets or patterns of chess pieces, often in less than a second (deGroot, 1966). However, such judgement and decision making skills only confer an advantage on problems that are meaningful within the expert's domain. Often skills acquired in one domain are highly intra-domain specific, and only become generalised following extensive experience (Wiggins & O'Hare, 1993). Perferto, Bransford and Franks (1983) found that after inexperienced subjects had acquired knowledge in a specific situation, they failed to transfer the information to a novel situation, even though the two situations had similar characteristics. Unless a pilot is able to connect the intra-domain knowledge, it makes NDM and RPD difficult.

7. NDM Instruction

This document has continually emphasised the important relationship between NDM and operator experience. This relationship has implications if naturalistic, intuitive decision strategies are to be taught to inexperienced or novice pilots. Despite the problems of this implication, little has been done in formulating techniques and strategies to teach intuitive decision processes. The topic has been treated rather like that of weather-related decision making for pilots, that is, it is assumed that the trainee will eventually learn through experience. Unfortunately, learning by experience is not always an effective, efficient, practical or safe practise in aviation (Simpson & Wiggins, 1997). Several authors have briefly covered areas of NDM that could and should be taught to inexperienced pilots, but literature and ideas on how this could be accomplished is very limited. There are two possible ways to improve NDM; decision training and decision aiding. The following section examines these two options, although it concentrates on decision training rather than aiding.

7.1 Decision Aiding

Decision making aids in the form of computers can help decision makers by computing and depicting situational features that are important for selecting a course of action (Noble, 1993). Decision aids focus on improving operator situation awareness because of the importance of this concept to NDM. Decision aids help the pilot by increasing the salience of the most significant aspects of the situation for its correct interpretation. The aids may also help by suggesting several effective courses of action. A decision aiding system should not become a decision making system, and it should never simply dictate decision courses to the operator. Rather, decision aiding can help less experienced pilots interpret a situation more as an experienced pilot would, by selecting and presenting the important information that an experienced operator would normally interrogate. Decisions aiding can also help an experienced pilot under stress interpret a situation more as they would when not under stress, by presenting specific information, rather than simply a large amount of data. If decision aids can help improve a pilot's situational awareness, then they will definitely aid in NDM.

Humans are inaccurate at estimating probabilities, and are particularly poor at revising probabilities based on new information (Mosier, 1991). Decision aids can be used to help improve this fault in decision making. O'Hare (1992) reports on the "pilot's associate", a decision aid for military pilots, consisting of both situation assessment and planning modules. It uses artificial intelligence to model the decision processes of pilots to increase the overall system performance. However, whilst such decision aids may be installed into fighter aircraft or battleships, due to size, weight and cost, they may not be feasible to install in light aircraft or small commercial aircraft. It is these aircraft that are often flown by the least experienced pilots, and hence are the pilots that would most benefit from the technology.

7.2 Decision Training

Whilst military platforms and large commercial aircraft may afford the luxury of decision aiding devices, it is impractical for small, general aviation aircraft to have powerful decision aiding computers on board. Because of this, pilot training is a good alternative. According to both Means et al. (1993) and Orasanu (1993), there is no evidence to suggest that it is possible to improve all-purpose decision making skills. Rather, specific components and skills need to be developed.

Several authors have discussed the validity of teaching "debiasing" techniques to pilots that impart awareness regarding the sorts of heuristics and biases that effect the decision process (Wickens, 1987). However, Means et al. (1993) argued that in debiasing the pilot, the trainer is extinguishing the natural and intuitive means of thinking, which is the basis of NDM. Reducing the use of heuristics and biases has proven to be hard to accomplish, and previous attempts have not been very successful, tending to be of limited generality and duration (Cook, Angus & Campbell, 1999).

Westerlund (1991) reported that the attitudinal and motivational dimensions of a pilot affect all decisions, thus training in this region may assist the decision process. Such motivations and attitudes encompass the "five hazardous thought patterns" of macho, invulnerability, resignation, impulsivity and anti-authority (Buch & Diehl, 1984). If pilots learn to control these hazardous attitudes then decision making may be more efficient and safe. Lester and Bombaci (1984) stated that these hazardous attitudes cause pilots to make decisions that are (in hindsight) inappropriate, counter-intuitive and often defy common sense.

Several researchers have discussed the importance of metacognition and self-evaluation training to improve NDM (Klein, 1993; Means et al., 1993; Orasanu, 1993). This is closely related to pilot awareness of hazardous attitudes, as metacognition training may allow pilots to become more aware and regulative of their cognitive processes and resulting behaviours. Learning to monitor decision making processes may mean that pilots are better able to manage time and realise when they have a workable solution, negating the need to search further. Although only speculative, it could be suggested that metacognition training may help inexperienced pilots from getting bogged down with information and options, allowing for faster, more intuitive decision processes.

Westerlund (1991) discussed the importance of information processing and recall of stored events in NDM. Jonsson (1991) discussed how relatively poor pilots are at revising decisions, and Senders and Moray (1990) suggested that pilots need training in "how to change one's mind" to "avoid cognitive lockup". Metacognitive training may help improve areas such as these, as it would allow pilots to be more aware of their capabilities and limitations. Pilots with good metacognitive skills have an overall better idea of their strengths and weaknesses, and potential problems, and hence can factor this into NDM to be more effective and flexible (Orasanu, 1993). The advantage of teaching metacognitive skills to pilots is that they are "the most trainable decision related skill complex" (Orasanu, 1993, p. 106), and are "the best candidate...that will aid decision making" (Means et al, 1993, p. 324). There is a sizeable literature on training metacognitive skills (Means et al., 1993). According to Means et al. (1993), such skills must be taught in the context of practising domain-relevant decisions; general metacognitive skills cannot be taught in isolation, as students do not learn how to incorporate these skills into NDM situations. Once pilots do understand how to be metacognitive in specific situations, they can start to apply the skill to general situations.

Training in situational assessment and mental simulation is of prime importance to NDM. Several studies cited in O'Hare (1992) described how pilots "lack the big picture" (p. 7), and suffer from "route tunnel vision" (p. 7) as well as having demonstrated "widespread deficiencies in acquiring and interpreting ... information" (p. 7). Such findings emphasise the idea that situation awareness skills are lacking in inexperienced pilots and need to be improved. Although most researchers agree with this, few suggest how it should be done. Orasanu (1993) suggested that situational awareness could be improved with considerable pattern recognition practise, and the development of mental models of the aircraft and related systems. She stated that

crews must be trained to rapidly recognise situational patterns that trigger stored memory templates of events, and pilots must then learn the response side of the pattern. For example, an engine failure in a light twin is met by an almost automatic pilot reaction (an example of RPD) due to the continual practice of it. Crews need to be trained to pay attention to ambiguous, unexpected or abnormal cues, as these often lack saliency, and could hold vital information for situation assessment and recognition (Orasanu, 1993).

Mental simulation requires teaching to enable pilots to anticipate future events and decision outcomes, as well as critiqueing their own plans. From training in mental simulation, pilots may be able to learn to accept that their plans may need modification, or completely new plans may need implementing. Closely tied in with the teaching of situation assessment and mental simulation, is the teaching of shared mental models. By teaching aircrews effective communication and interaction skills, shared mental models may be developed more effectively, allowing for better NDM.

Kaempf and Klein (1993) described several other skills that may need training in pilots, including risk assessment and resource management. Pilots need to understand that safety is of paramount importance, and risks need to be minimised. This ties in with metacognition and hazardous attitude awareness and training. Orasanu (1993) stated that resource management needs to be taught to pilots, as it impacts on the quality of decisions they make. Resource management is closely related to metacognition, as effective resource management can help crews reduce the demands on their own cognitive resources, especially at times of high workload. Effective resource management allows for flexibility in situations, which is an important part of NDM. Teaching resource management involves several things including, imparting an understanding in pilots of what must be done in most decision situations, how to identify and use all available resources, how to manage time and resources (including crew) effectively, and an understanding of how to prioritise tasks (Orasanu, 1993). These features of resource management are very similar to what is taught in crew resource management courses (CRM) and hence, the teaching of this area of NDM can be modelled from the CRM courses.

The general consensus of all the above mentioned training, is that for maximised effectiveness it should be taught to pilots in naturalistic environments, ie, time pressure, high workload, uncertainty, dynamic, other people involved etc.

8. Conclusion

It has been determined through several studies that experienced operators (including pilots) in their operational settings make many decisions using intuitive rather than analytical strategies. NDM is one such strategy in these naturalistic environments, and RPD is one of the most widely described models of NDM. Naturalistic strategies describe how experienced people make decisions under conditions of time pressure,

dynamic environments and goals, uncertain cues and high risk. All of these characteristics are found in aviation environments.

The earlier sections of this report examined the principles of NDM, detailing theoretical perspectives that explain how NDM and RPD work, and how such skills are acquired, including how the situation recognition actually occurs. Intuitive and analytical decision making strategies were compared and contrasted, highlighting the appropriateness of intuitive methods (NDM and RPD) to operational settings such as aviation.

The key features of NDM and RPD were examined. A discussion of the RPD model demonstrated the importance of situational assessment and mental simulation to NDM. The importance of expertise and experience was a theme running throughout the report, and the differences between expert and novice decision making were presented. It would seem that only experienced pilots would be capable of implementing RPD due to the reliance on memory traces and pattern recognition.

The final section of this document addressed decision aiding and instruction, and areas of NDM and RPD that may be able to be taught to novices and inexperienced pilots were examined. Although there has been little work done to formulate teaching strategies for NDM and RPD, some ideas were presented. It appears possible to teach novice pilots at least the basics of NDM, which they can then develop themselves.

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19. ABSTRACT

The majority of accidents and incidents in aviation can be attributed partially to poor decision making and judgement strategies. By gaining an understanding of aircrew decision strategies used in the operational environment of the cockpit, it may be possible to improve decision processes and outcomes for both expert and novice pilots. Naturalistic decision making (NDM) is proposed as an intuitive decision strategy used by experienced pilots to make operational decisions. The cockpit is considered a naturalistic environment due to characteristics such as experienced operators, multiple players and teams, dynamic conditions, shifting and competing goals, high risks, time pressure, and ambiguous or missing data. NDM strategies focus upon situation assessment and the serial evaluation of decisions through mental simulation. Decision aiding to improve situation assessment and decision training to impart awareness of the limitations and weaknesses (heuristics and biases) of human decision processes are both aimed at improving the overall decision performance of both expert and novice pilots. The overall aim is to improve aviation safety and reduce the number of accidents and incidents due to poor decision making and judgements.

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